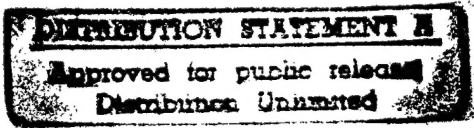


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Waves in Plasma Sheaths and at Boundaries  
Theory and Computer Experiments

AASERT Annual Progress Report  
9/1/95 - 8/31/96

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Electronics Research Laboratory

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Office of Naval Research  
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# ONR Progress Report '96: Sheath Waves

## Summary of current and future research

Our 2d3v simulations have added to the detailed understanding of sheath waves in metal bounded plasmas. We define sheath waves as surface waves which propagate along a plasma/sheath interface. Sheath wave modes analogous to Gould-Trivelpiece waves (which exist in dielectric bounded cylindrical plasmas) have been measured in electrostatic PIC simulation of a metal bound plasma slab. Thermal excitation (linear regime) of these normal modes has been sufficient to measure both real and imaginary components of the sheath wave dispersion relations,  $\omega(k_y)$  where the waves propagate along the y-axis and the x-axis is perpendicular to the plasma slab. A time averaged power spectral density of the signal  $\phi(x, k_y, t)$  in  $\omega$ -space was used to measure this dispersion. By computing the PSD at varying x positions, the eigenfunctions of the perturbed wave potential were measured.

Additional sheath wave modes, whose  $k_y = 0$  cutoffs represent Tonks-Dattner resonances of a plasma slab, have also been measured. The experimental measurement of the spatial eigenfunctions of these modes (Fig. 1) suggests good qualitative agreement with the prior theoretical work of Parker, Nickel and Gould[1] who predicted that Tonks-Dattner resonances resulted from the trapping of a longitudinal plasma wave between a bounding wall and an internal turning point.

This detailed study of the linear behavior of sheath waves in a plasma sustained by external means (typically uniform ionization) has been followed by an investigation of sheath wave sustained plasmas. Early work has been limited to 1d3v simulation in which the sheath wave is driven at its cutoff frequency to resonantly sustain the plasma discharge. This cutoff is known as the **series resonance** since its frequency  $\omega(k_y = 0)$  represents the point at which the series capacitance of the sheath regions and the plasma regions cancel. Resonantly sustained discharges have been observed at varying plasma and neutral species densities (Fig. 2). Scaling laws predicted by Godyak[2] have been demonstrated in our simulation. Also, for sufficiently low neutral species densities, as in conventional (low frequency  $\omega_{rf} \ll \omega_{pe}$ ) capacitively coupled discharges, a large deviation from a single Maxwellian distribution of electron energies is observed.

There are several additional step to be taken, as follows.

Observation of electron heating exhibits large spatial oscillation near the plasma/sheath boundary indicating the likelihood of different heating mechanisms than observed in non-resonant discharges. These observations (Fig. 3) serve as a motivation to further study the mechanism by which these resonantly sustained discharges are heated.

Large area discharges may be sustained via the excitation of a standing sheath wave. Such a device may be of particular applicability to materials processing where large area, uniform plasmas are desired. This possibility has served as a motivation for developing a doubly bounded, electromagnetic PIC

code with which preliminary simulations have proven that standing sheath waves can in fact sustain a discharge. Further investigation is needed to characterize the plasma dependencies along the parallel direction., e.g. density profiles, uniformity of energy deposition.

There are also some more speculative ideas to be considered, such as the application of microwave sheath waves to enhance plasma uniformity in traditional capacitively and inductively coupled discharges.

## References

- [1] J. V. Parker, J. C. Nickel and R. W. Gould, *Phys. Fluids* **7**, 1489 (1964).
- [2] V. A. Godyak, **Soviet Radio Frequency Discharge Research**, (Delphic Associates, Falls Church, VA, 1986)

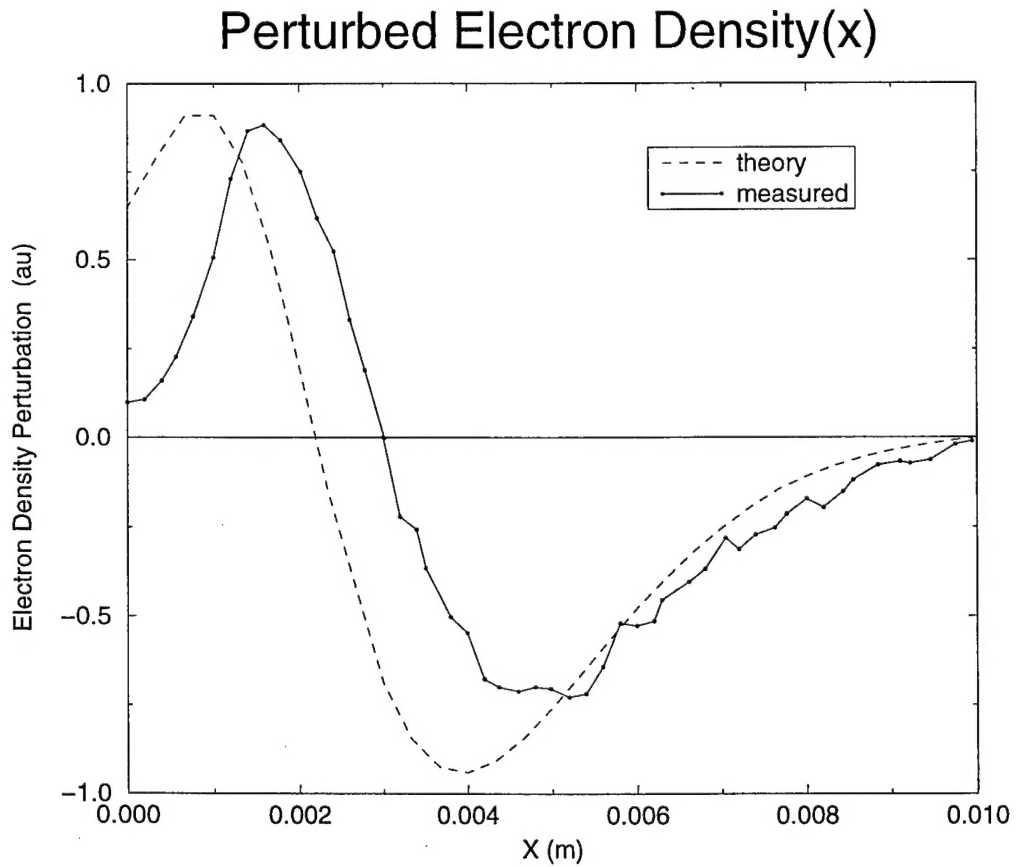
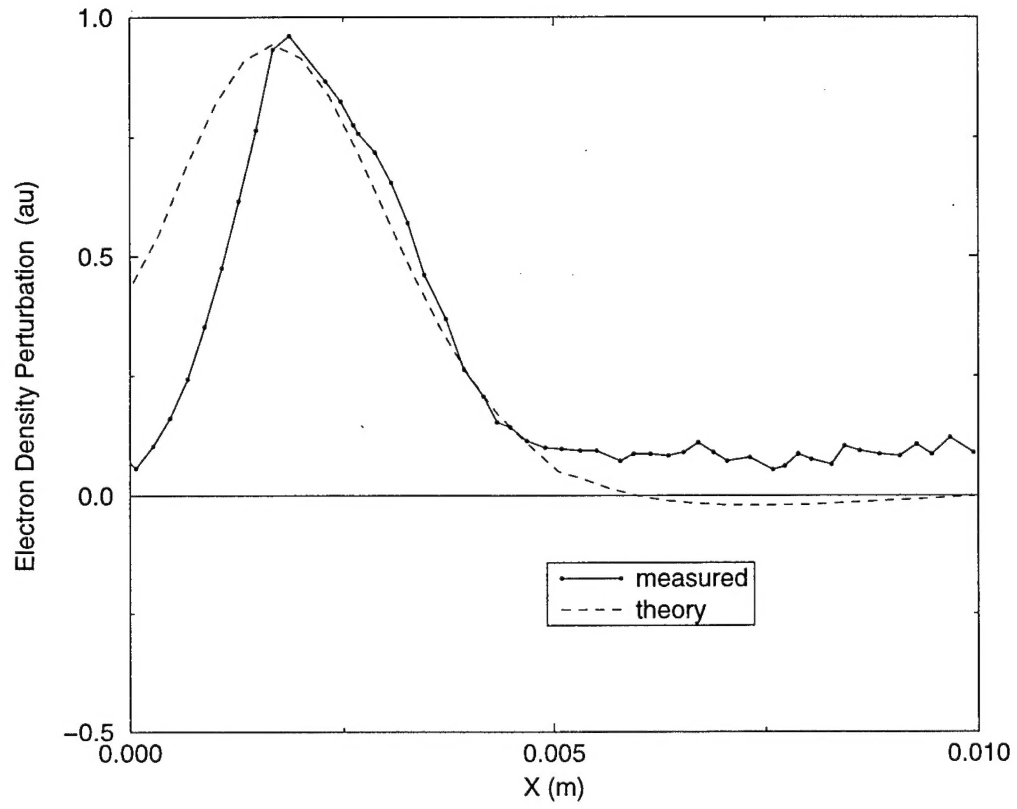


Figure 1: Electron density perturbation of the asymmetric main resonance (top) and the first Tonks-Dattner resonance (bottom). The mid-plane of the plasma slab is at  $x = 0.01m$ .

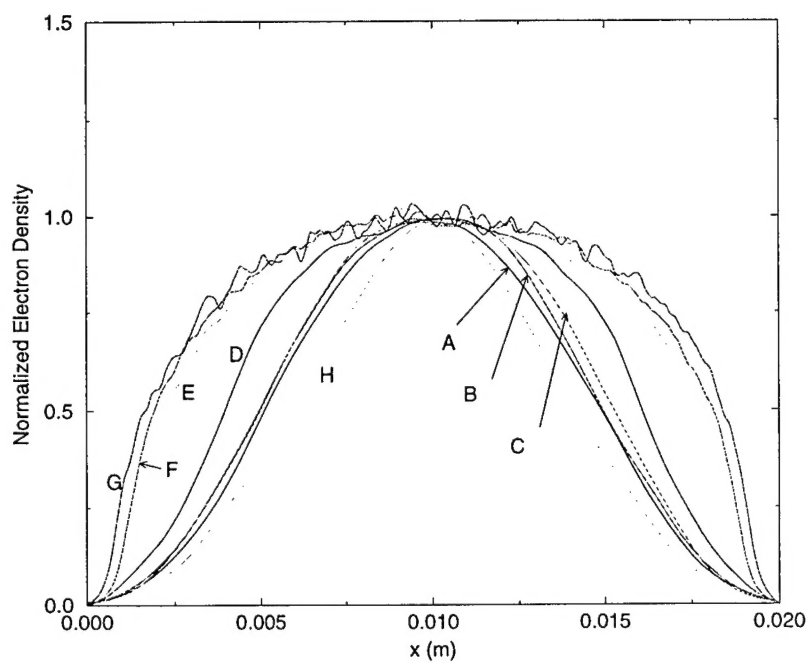


Figure 2: Normalized density profiles for series resonance sustained discharges. Peak densities range from  $10^9/cm^3$  (case A) to  $10^{11}/cm^3$  (case G).

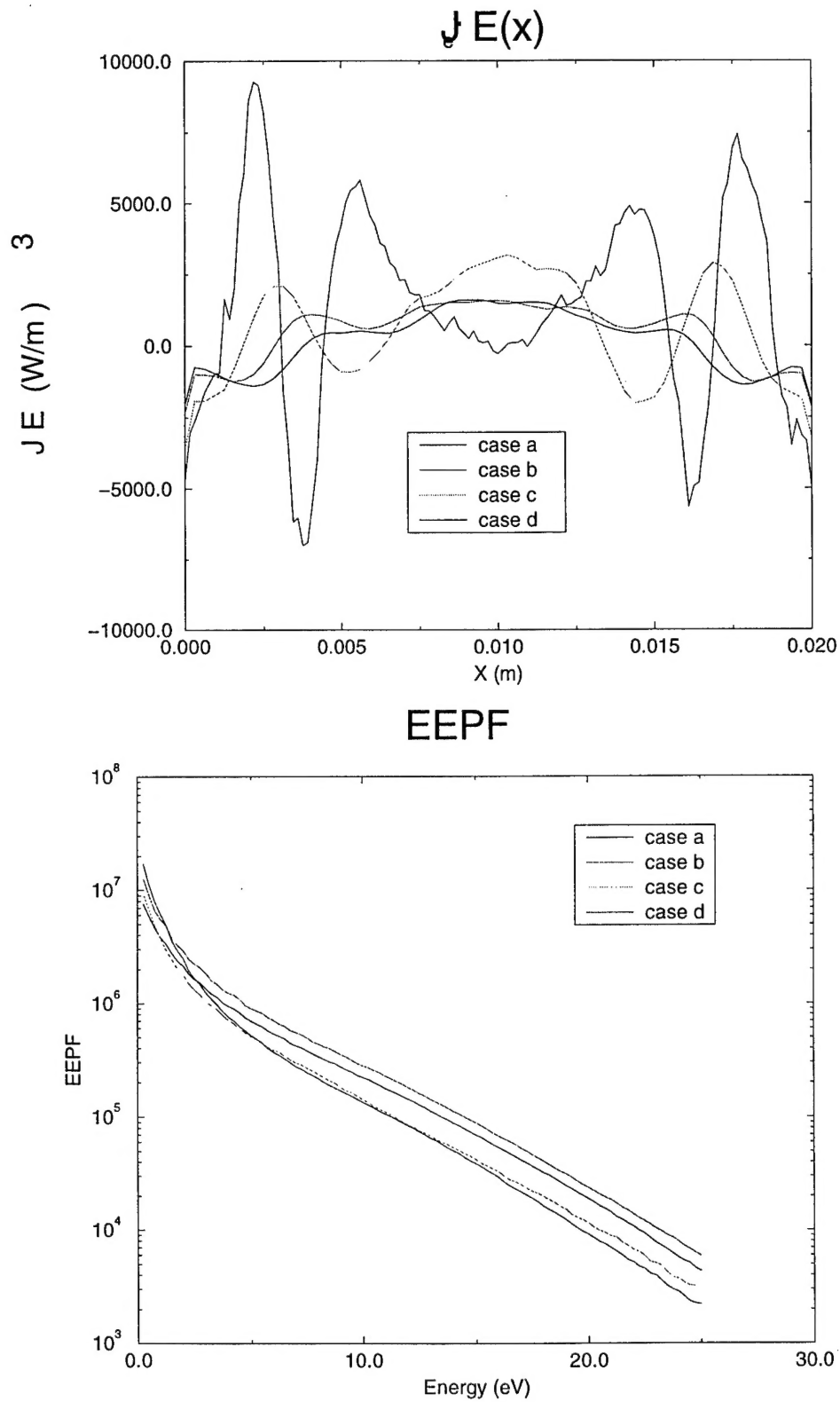


Figure 3: Electron heating profile (top) for discharges of various peak densities,  $10^9/cm^3$  (case A) to  $10^{11}/cm^3$  (case G). Electron energy probability functions for these experiments (bottom).